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February 1984

POTENTIAL IMPACT OF OCEAN THERMAL ENERGY CONVERSION (OTEC) OPERATION ON FISHERIES

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Not for Publication

ADMINISTRATIVE REPORT H-84-4

I. INTRODUCTION

A collaborative study to address the potential impact of ocean thermal energy conversion (OTEC) operations to fisheries was initiated between the Office of Ocean Minerals and Energy (OME) and the National Marine Fisheries Service (NMFS) in June 1982. Since then, several substudies describing the OTEC operating conditions, the compilation and syntheses of pertinent biological and fishery information, syntheses of information on entrainment, impingement, biocides, nutrients, trace metals and attraction-avoidance effects have been completed.

This report documents the potential impact of OTEC operations on fisheries based on the various substudies.

II. OPERATING CONDITIONS

The basic requirement for an OTEC plant is an adequate temperature difference, an annual minimum difference of 20°C, between the surface water and water at a depth of about 1,000 m. Warm water drawn from the ocean's surface provides heat which is transferred through a heat exchanger to a working fluid. The working fluid is evaporated and the resulting high-pressure vapor is used to drive a turbine to produce electricity. Cold water pumped from the deep condenses the subsequent low-pressure vapor in a second heat exchanger, and the working fluid is then pumped back and recycled. The mixture of warm and cold water is discharged at a depth where it will be least harmful to the environment (Uchida 1983).

A. OTEC Sites

Areas of a minimum difference of 20°C between surface and deep water can be found year round over a vast expanse of the oceans in the tropics between lat. 20°N and 20°S. However, sites that would provide maximal usage by an OTEC plant would be governed also by other criteria, such as, bottom topography and profile, tidal, wind-driven and inertial currents, mass transport by waves, climatic conditions, and economic zone considerations. The last could affect the placement of floating plant ships in open waters where the economic zones of two or more countries overlap, but will not be a concern to shoreside or nearshore facilities, which will be well within the zone.

Uchida (1983) lists a number of places that would be adequate for possible land-based OTEC facilities in the Pacific. These include the Hawaiian Islands, Cabras Island off Guam, Manila, the Republic of Nauru, Taiwan, Mexico, French Polynesia, and New Calendonia. Hoss et al. (1983) list Puerto Rico and the Virgin Islands as possible localities that would be accessible to American corporations in the Caribbean Sea. At all of these localities one or more sites were identified as being suited for OTEC operations.

Sites for early U.S. development of OTEC plant operations have been narrowed to Kahe Point, Oahu, Hawaii near the O'OTEC benchmark sites (Fig. 1) in the Pacific, and southeastern Puerto Rico (Fig. 2) in the Caribbean. In both places depths of 1,000 m are located within 3.8 nmi from shore.

B. Site Characteristics

1. Temperature, salinity, and density profiles

Off Kahe Point the surface temperature varies from 24.1°C in winter to 26.9°C in summer and has a range of ±1.2°C in both seasons. The temperature ranges from 5.2 to 5.5°C at 700 m and is about 4.2° at 1,000 m. The depth of the surface mixed layer varies from 10 to 140 m, and the most probable depth varies from 40 to 100 m. The mixed layer is shallowest in summer and deepest in winter. The salinity near the surface is about 34.84 ppt, and a salinity maximum of 35.10 ppt is at a depth of 100 to 125 m and a salinity minimum of 34.15 ppt at a depth of 450 m. The density profile is dominated by the temperature, but salinity variation has some effect especially because the salinity maximum occurs near the thermocline (Ditmars and Myer[1]).

Off southeastern Puerto Rico the temperature varies from 26.2°C in winter to 29.2°C in summer and has a range of ±1.5°C in both seasons. It is 7.9°-8.2°C at 700 m and 5.3°C at 1,000 m. The depth of the mixed layer varies from 10 to 140 m. The salinity is about 35.1-36.1 ppt at the surface, and 36.7 ppt at 100-175 m; a salinity minimum of 34.9 ppt is at 700-900 m (Ditmars and Myers footnote 1).

2. Currents

Being combinations of tidal currents, geostrophic flow, and wind-driven currents, the currents off Kahe Point are fairly complex. These currents are highly variable in magnitude and direction. The semidiurnal tidal current is 20-30 cm/s, the diurnal tidal current is 10-20 cm/s, the geostrophic flow is about 15-25 cm/s, and the wind-driven current ranges from 9 to 10 cm/s. The flood-tide current and wind-driven currents roughly parallel the shoreline. The mean flow is estimated to be about 10 cm/s or less, and the net flow of the surface waters tends to be generally westward (Ditmars and Myers footnote 1).

In the vicinity of southeastern Puerto Rico, the currents generally flow westward, parallel to the shoreline. The mean current is typically 10-40 cm/s in the deep offshore waters (>1,000 m) and slightly higher (ca. 60 cm/s) near shore (Ditmars and Myers footnote 1).

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[1]Ditmars, J. D., and E. P. Myers, National Marine Fisheries Service Argonne National Laboratory and National Ocean Service, Chicago, IL. Preliminary estimates of the range of operating conditions expected for initial OTEC deployments. Manuscript prepared for OTEC Program, Office of Ocean Minerals and Energy, Washington, D.C.

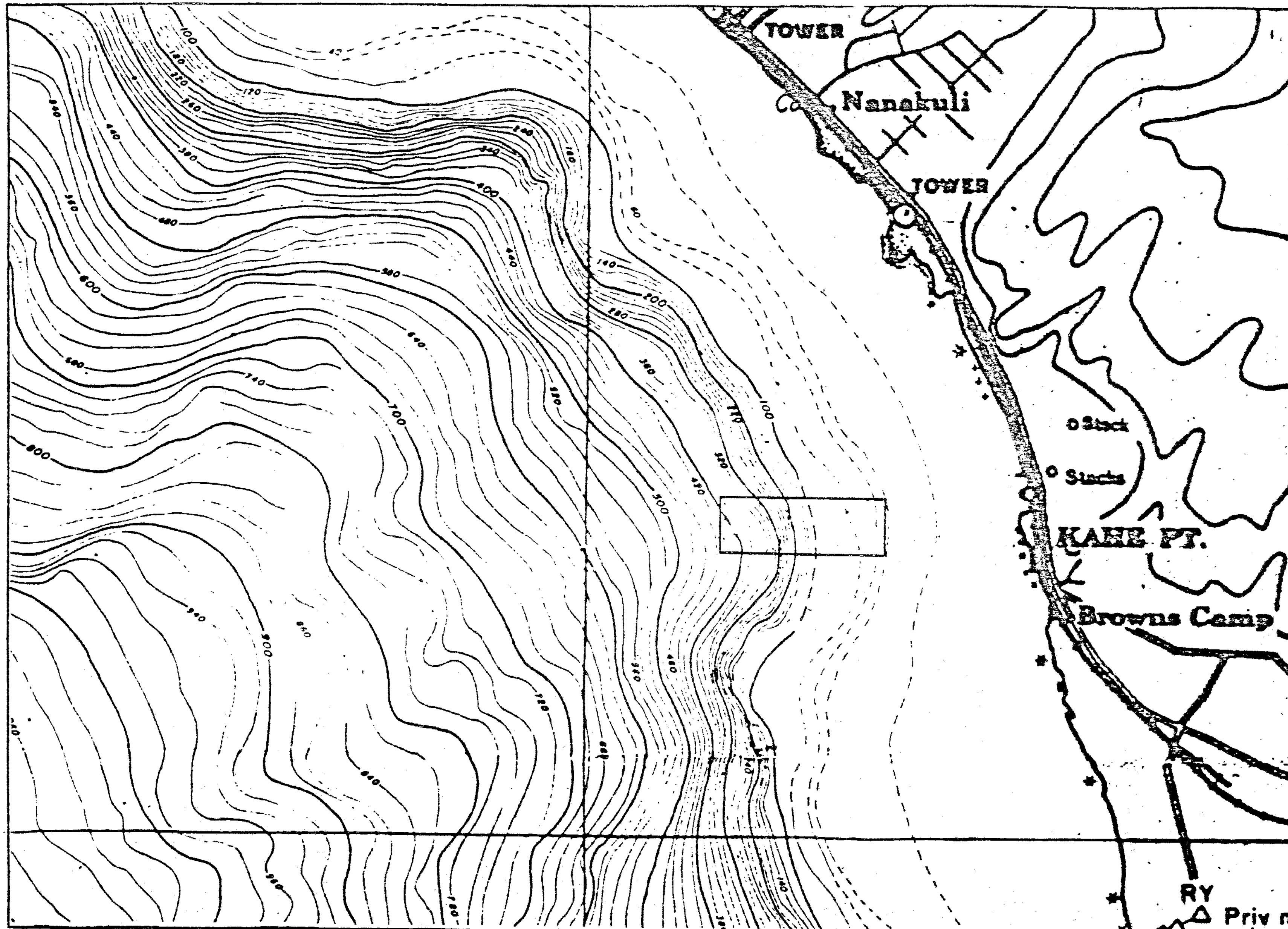

Figure 1.--Potential OTEC site off Kahe Point, Hawaii.

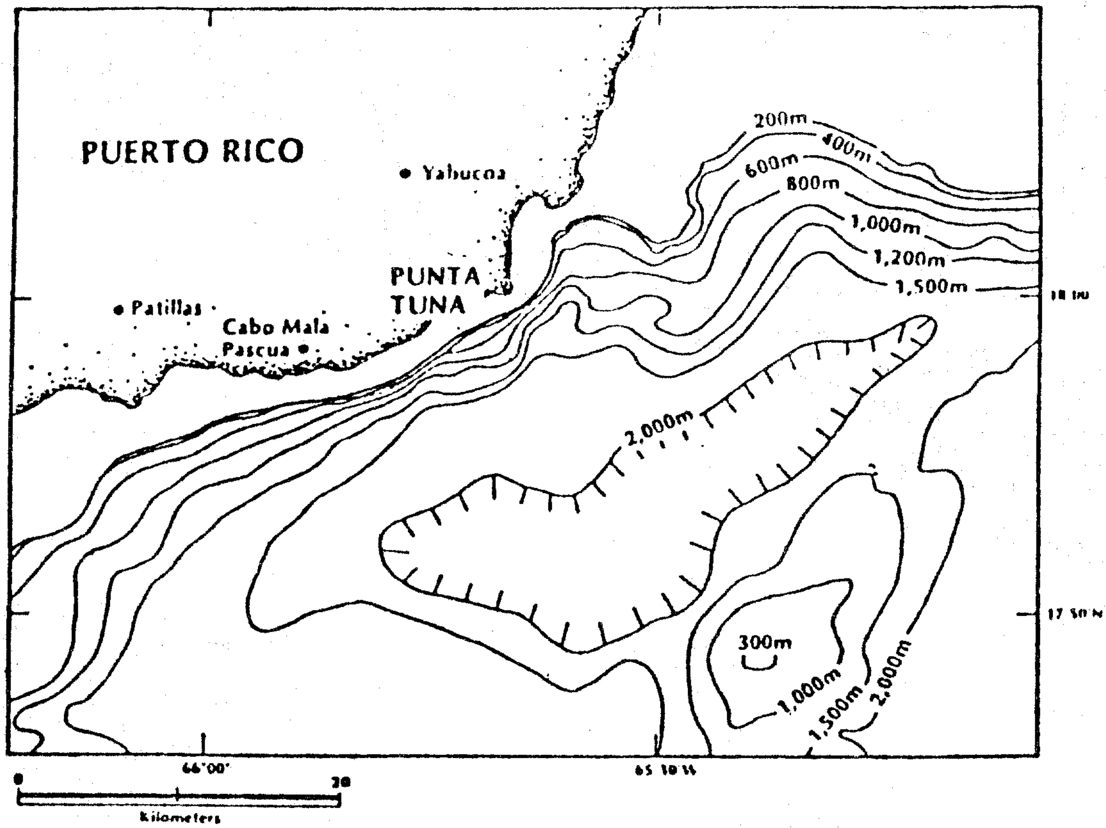

Figure 2.--Bathymetry near potential OTEC site at Punta Tuna, Puerto Rico (Sullivan et al., 1981).

C. Plant Characteristics

1. Type, capacity, and dimensions

General plant characteristics for OTEC are addressed in Ditmars and Myers (footnote 1) and are briefly summarized here. The first OTEC plants are expected to be of the closed-cycle type using ammonia as the working fluid (Fig. 3). They will be small, about 40-MW and will probably be located on or near shore or on bottom-mounted towers in about 100 m of water. A typical shore-mounted plant might be made of four 10-MW units and have horizonal dimensions of about 100 m. Bottom-mounted plants (on towers) will utilize the space along the vertical extent of the tower and thus will have horizontal dimensions of about 50 m. The heat exchangers will be made of aluminum or titanium and biofouling will be controlled by periodic chlorination.

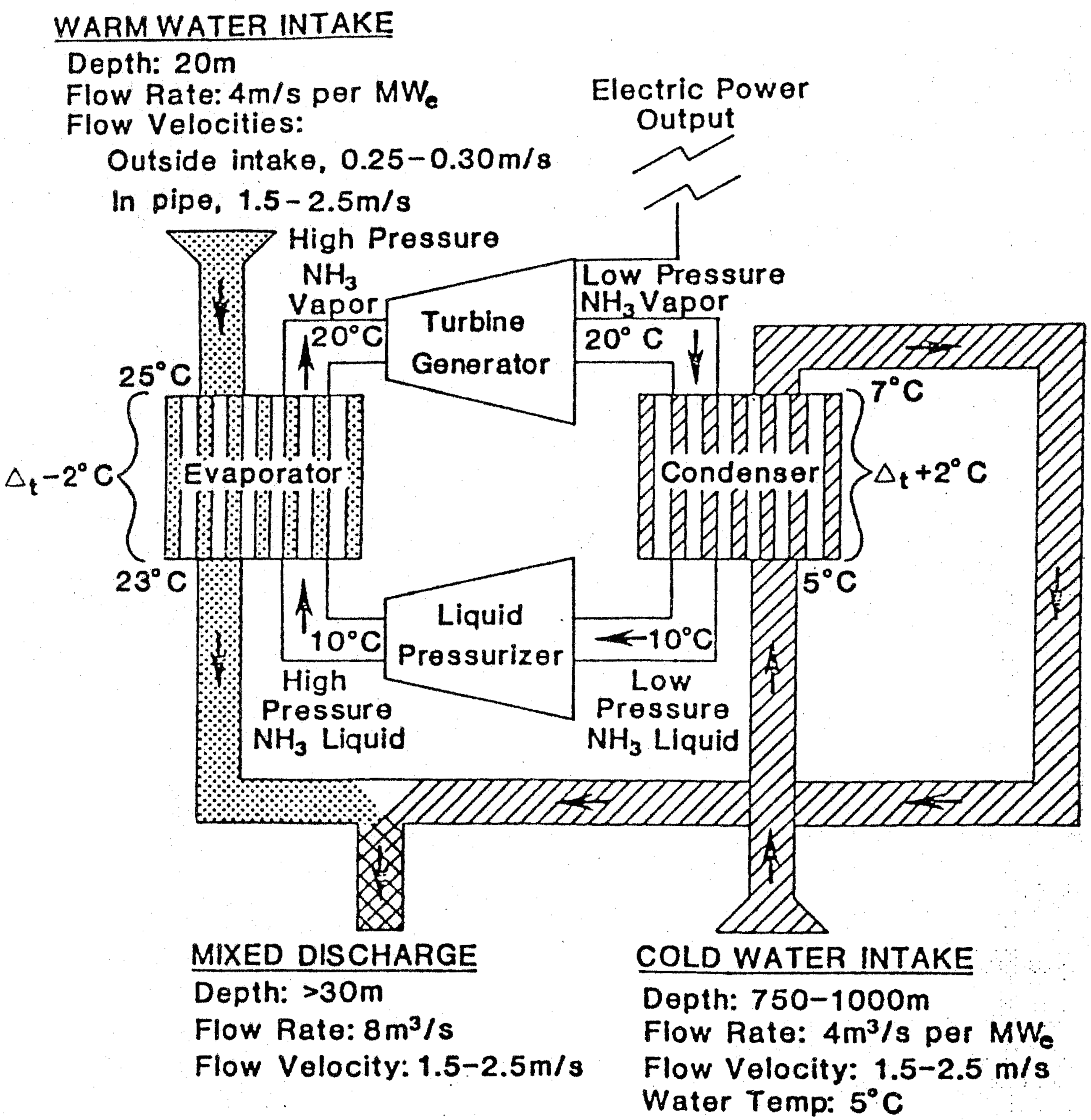

Figure 3.--Schematic diagram of a closed cycle OTEC system (Hoss and Peters 1983).

2. Operation

a. Warm and cold-water intakes

The warmwater intake pipe will be 9.2 m in diameter and the intake will generally be located between 10 and 20 m deep, depending upon the size of the plant. The intake structure will be modified so that the horizontal dimension will be larger than the vertical dimension to reduce the intake velocity. Thus, whereas the velocity of flow in the pipes will generally be in the 1.5-2.5 m/s range, that outside of the intake structure will be 0.25-0.30 m/s. The typical warmwater flow rate will be about 4 m^3/s/MW. At this flow rate, roughly 13.8 x 10^6 m^3 of water will flow through the warmwater intake in a 40 MW plant each day.

A screen placed at the intake will prevent large organisms from entering the water system and clogging the heating pipes in the heat exchangers. The screen mesh size is not known; however, following a generally accepted criterion that mesh size should equal half the diameter of the heat exchanger tube and based on the projected size of exchanger tubes plants, the screen mesh size could be about 1.3 cm (Sands 1980).

The cold-water intake pipe also will be 9.2 m in diameter and 915 m long. Because the cold-water intake will be too deep to monitor the intake screen, the water will be passed through a sump within the plant where a screen could be placed to strain out the large organisms. The cold-water flow rate (4 m^3/s) and the velocity of flow in the pipe (1.5-2.5 m/s) will be comparable to those in the warmwater pipe.

b. Discharge

Most OTEC designs try to locate the discharge so as to reduce the potential for recirculation into the warmwater intake and depend on the density of the effluent being greater than that within the mixed layer so that the effluent will come to equilibrium below the mixed layer. The discharge port or ports are usually the open end of a round pipe directed either downward or horizontally, often with a downward component. For nearshore plants this may involve the use of discharge pipes leading offshore. In deeper waters the discharge will be located generally deeper than 30 m, most likely at 100 m, to avoid recirculation into the warmwater intake pipe.

The discharge flow rate will equal the intake flow rates of both cold and warm water. For a 40-MW plant, Wang[2] states that the flow rate of the 15°C mixed discharge water will be 280 m^3/s, that in the open ocean, the

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[2]Wang, D.-P. National Marine Fisheries Service Argonne National Laboratory. A far-field model for regional influence of OTEC operation. Manuscript prepared for OTEC Program, Office of Ocean Minerals and Energy.

near-field effect of the effluent is characterized by a jet with high initial speed (order 1 of m/s) and rapid dilution (order of 10), that the far-field effect is characterized by a buoyant plume which will drift at about the ambient ocean current speed and spread laterally due to gravity, and that the transition from a near-field jet to a far-field plume typically takes place at a distance of a few hundred meters from the plant.

III. FACTORS THAT MAY AFFECT FISHERIES

The OTEC operation will withdraw large volumes of warm and cold water. The major impacts of this withdrawal are impingement of organisms on the intake screens, primary entrainment of organisms through the OTEC plant, and the deleterious effects of the discharge on the environment (secondary entrainment). The type and degree of impact will depend largely upon the location of the intake, the rate of withdrawal, and the density of organisms at the intake and discharge. In general, phytoplankton, zooplankton, and micronekton can be expected to sustain maximum effects, whereas the nekton will suffer lesser effects. Those fish whose entire life stages, from zooplanktonic to nektonic, occur at the intake depths will be subjected to impingement and entrainment.

A. Impingement

Impingement occurs when organisms too large to pass through the intake screen are pulled against it and are unable to escape due to the force of the withdrawn water. Screen mesh size, biomass concentrations, and volume of water circulated are primary factors of impingement. In most fishes, body length is usually three times the body depth, so that fish larger than about 4 cm long and with limited avoidance capabilties may be impinged on the intake screens. Those with deeper or wider bodies will be impinged at smaller sizes.

The only available information on the density of fish that is usable to estimate the effects of OTEC operation is from midwater trawl tows. Based on such data from an area farther offshore (10-25 km) and to the north of Kahe Point (Maynard et al. 1975), Sands (1980) estimated that 130 kg of micronekton would be impinged daily in the warmwater screen and 82 kg in the cold-water screen, in a 40-MW plant. Since fish comprised 51.9% in weight of the micronekton standing stock (Maynard et al. 1975), the estimated biomass of fish impinged would be about 67 kg per day on the warmwater screen and 43 kg per day on the cold-water screen.

B. Primary Entrainment

Marine organisms small enough to pass through the 1.3 cm intake screen (Sands 1980) will be entrained in the seawater flowing through the heat exchangers and be exposed to various stresses resulting from rapid changes in temperature and pressure, abrasion and collision with structures, and exposure to biocide and other toxic substances that might result from plant operation.

1. Temperature

Organisms passing through the OTEC plant will be exposed to cold and warm thermal effects. Fish eggs and larvae entrained in the warmwater intake pipe will be exposed to sudden cooling as the warm intake water (26°C) is mixed with the cold intake water (5-7°C), and to sudden warming as the mixed water (about 15°C) is ultimately discharged at a depth of about 100 m. At Kahe Point, the ambient temperature at this depth is 21-24°C (Noda et al. 1981). The entrained fish eggs and larvae thus will be exposed to successive changes in temperatures of -11°C at mixing and +6°-9°C at discharge. Although the exposure time in the mixed water will be brief (<1-2 min), the cold shock of -11°C may be large enough to cause fish larvae and juveniles to lose equilibrium and thus become susceptible to increased predation, and eggs and larvae to suffer mortalities.

Susceptibility to increased predation has been found for juvenile channel catfish exposed to cold shocks of -6°C or more (Coutant et al. 1976), and young bluegill exposed to cold shocks of -9°C (Wolters and Coutant 1976). Juveniles of American shad acclimatized at 21.1°C suffered mortalities of 90 and 100% when exposed to cold shocks of -8.3° and -13.9°C, respectively (Tagatz 1961); mature alewife acclimatized at 21°C suffered 30 to 100% mortalities when exposed to cold shocks of -10.5° to -16°C (Otto et al. 1976), and shad that had lost equilibrium from cold shock for 12 s before being returned to warm water suffered as much as 32% mortality (Griffith 1976). Although these were all freshwater fish, similar effects could prevail among marine species.

Fish eggs, larvae, and juveniles entrained in the cold-water intake pipe will be exposed to sudden warming of +10°C at mixing and another 6°-9°C at discharge, for a total t of 16°-19°C. Exposure to a t of this magnitude could result in loss of equilibrium among larvae and juveniles and even mortality in all three growth stages. Schubel and Koo (1976) observed that hatching success of eggs of blueback herring and American shad was significantly reduced at a t of 15°C in exposures of 10 min or longer and that excess temperature of 20°C resulted in nearly total mortality of the eggs. Other studies indicate that thermal shocks of 8°C produced moderate mortality in larvae of Atlantic silverside reared in 25°C water (Austin et al. 1975) and young alewife acclimatized at 10°C suffered 30, 60, and 100% mortalities in abrupt temperature increases of 16°, 16.5° and 17°C, respectively (Otto et al. 1976).

If oceanic fish eggs and larvae react to thermal changes in a similar manner, mortalities to those entrained in OTEC plant operations could be substantial. Based on the average densities of fish eggs and larvae at depths of 600-1,000 m off Kahe Point (data from Noda et al. 1981) and on the estimated intake flow rate, an estimated 48 million fish eggs and 83,000 larvae could be entrained daily in the cold-water intake and thus become exposed to thermal effects.

2. Biocides

Chlorine will most likely be used in OTEC plants to control biofouling. The U.S. Environmental Protection Agency (EPA) guidelines restrict the discharge of free chlorine to 2 h in any 1 day (EPA 1976). The allowable discharge concentration during these 2 h must average 0.2 ppm over 30 days, with a maximum of 0.5 ppm. At these levels of concentration, the majority of entrained organisms could be affected (Morgan and Carpenter 1978), how-ever, damage to the organisms would be reduced greatly if exposure times are short. Effects on fish vary with age; larvae are more susceptible than juveniles, and eggs are more tolerant.

A recent study (Venkataramiah et al. 1981) on the toxicity of OTEC plant components on marine organisms has shown that total residual chlorine level of about 0.1 ppm or lower was not lethal to the test animals (juvenile mullet, Mugil cephalus, 25-75 mm long) and that 100% mortality occurred at a concentration of 0.289 ppm after 6.5 h of exposure. The study also indicated that toxic concentrations were size related, the resistance to chlorine increasing with fish size. Other studies on eggs and larvae showed that 0.032 ppm of free chlorine produced 50% mortality in early larvae of plaice, but there was no effect on eggs at chlorine levels of 0.75 ppm in an 8-day exposure (Alderson 1972); LC_{50} values for different stages of plaice and Dover sole larvae were below 0.10 and above 0.025 ppm at exposures of 48 and 96 h, respectively (Alderson 1974); and striped bass juveniles approximately 63 mm did not show significant mortality until after 1 h exposure to 0.16 ppm residual chlorine at t of 6.8°C (Lanza et al. 1975).

Since the exposure time through the plant is expected to be short (about 10-15 min in warmwater systems, 20-30 min in cold water systems), damage to entrained fish eggs and larvae from biocide may be relatively low. Assuming the worst situation, i.e., the larvae suffering 100% mortality and treatment applied for 2 h each day, at least 115,000 larvae could be expected to die daily in the warmwater system and 11,500 in the cold-water system from biocide treatment alone.

3. Physical damage

Fish eggs and larvae entrained in cold and warm intakes will be subjected to stresses similar to those encountered in powerplants. They will be stressed by rapid changes in hydrostatic pressure, velocity shear forces, buffeting and collision with other organisms, and collision with fixed or moving equipment, such as screens, piping and pumps (Marcy et al. 1978). Organisms entrained in the cold water pipe will be exposed to pressure changes of up to 100 atmospheres within a few minutes (Sands 1980). Entrained larvae and juveniles possessing a swim bladder would be vulnerable to pressure changes of this magnitude and would suffer mortality (Blaxter and Hoss 1979; Hoss and Blaxter 1979).

Studies on the effects and impacts of physical stresses on organisms entrained in powerplants (Marcy et al. 1978) show that fish eggs and larvae of many species of fish, including freshwater, estuarine, and some marine species, suffered substantial mortality ranging from 30 to 100%. For most species, the mortality was between 90 and 100%. A similar study by Serchuk (1976) shows that juveniles fared better; total mortality ranged from 56.5 to 67.7%. Generally, physical damage was the major cause of mortality of entrained organisms, and the greatest damage occurred during passage through the pumps.

Whereas damage from biocide treatment is intermittent, damage from physical stresses will be continuous during the entire period the plant is in operation. Consequently, some investigators (Hoss and Peters 1983) believe that the major cause of entrainment mortality will be physical damage.

C. Secondary Entrainment

Most of the same stresses encountered in primary entrainment will also be encountered in secondary entrainment. These include stresses resulting from temperature changes, use of biocides, and turbulence caused by the mixing of the effluent with the surrounding water.

At the expected discharge depth of 100 m off Kahe Point, the 15°C effluent will mix with 21°-24°C water. Fish eggs and larvae in the latter would thus be exposed to a cold shock of -6° to -9°C followed by a rapid return to ambient temperature. Exposure to this cold shock could result in loss of equilibrium and some mortality.

Stress from biocide could occur among organisms entrained in the plume, largely as a result of prolonged exposure; however, rapid dilution of the effluent, resulting in reduced chlorine concentration and exposure time, could effectively reduce or eliminate stress from this source. The centerline dilution and chlorine concentration in the discharge plume is given by Sands (1980). With a 0.2 ppm chlorine concentration at the point of discharge, dilution to 0.05 ppm will occur at a downstream distance of 0.2 km. Based on a current flow of 11.1-18.4 cm/s at that depth (Noda and Associates 1982), this dilution will be reached in 0.3-0.5 h; dilution to 0.02 ppm will occur at a distance of 2.5 km in 3.8-6.2 h; and to 0.01 ppm at 5.0 km in 7.5-12.5 h. Comparing these values with the LC_{50} values for plaice, 0.10 ppm in 48 h exposure, and Dover sole larvae, 0.025 ppm in 96 h exposure (Alderson 1974), it would seem unlikely that the chlorine concentration in the OTEC plume will be harmful to fish larvae.

Physical damage to fish eggs and larvae could be caused by acceleration and shear forces in the turbulent eddies created by the discharged water. Only limited studies have been made on the effects of acceleration and shear forces on aquatic organisms, and these have dealt mainly with passage of entrained organisms through powerplants (Marcy et al. 1978). Shear bioassay experiments by Morgan et al. (1976) indicated that juvenile _Morone_ spp. begin to suffer mortality when the shear stress approaches three times the force of gravity. Studies on determining the intensity and effects of turbulence created by the discharge from OTEC plants have not been made. It is, therefore, difficult to predict the impact resulting from turbulence in secondary entrainment.

D. Attraction

The OTEC platform could act as a fish attracting device (Seki 1983) and congregate pelagic as well as inshore fishes. The lights at night will also attract juveniles and small fishes. The attraction will thus result in an increase of fish that would be susceptible to impingement and entrainment. Although the exact numbers of fish that ultimately become impinged and entrained in the plant intake systems cannot be estimated, due to the lack of sampling data, it could be significant.

IV. EFFECTS ON FISHERIES AT PREDICTED SITES

A. Hawaii

1. Fisheries affected

The most common commercially important species of fishes in Hawaiian waters are listed in Table 1. The major thrust of the commercial fishery is in the open ocean beyond the 200 m depth, where pole-and-line boats catch skipjack tuna, Katsuwonus pelamis, and longline, handline (ika-shibi), and commercial and recreational trolling boats, harvest deep- and surface-swimming yellowfin tuna, Thunnus albacares, bigeye tuna, T. obesus, albacore, T. alalunga, striped marlin, Tetrapturus audax, blue marlin, Makaira nigricans, black marlin, M. indica, swordfish, Xiphias gladius, shortbill spearfish, T. angustirostris, sailfish, Istiophorus platypterus, wahoo, Acanthocybium solandri, and dolphin, Coryphaena hippurus

Table 1.--Commercial fish catches for State of Hawaii: Year ending June 30, 1976[1] (Sands 1980).

Species	Weight (lb)	Value of catch sold (in dollars)
Aku (skipjack tuna)	6,891,039	2,911,061
Ahi (yellowfin tuna)	1,723,128	1,463,376
Akule	746,857	422,211
Opelu	291,337	231,236
Striped marlin	230,412	113,243
Opakapaka	147,505	165,195
Ono	132,104	90,448
Mahimahi	119,332	145,010
Ulaula koae	80,543	162,219
Uku	69,832	68,321
Kahala	40,434	21,822

[1]Average 5-year annual totals (1972-76) all species from commercial catches are weight: 13,259,377, value: $6,238,927.

(Uchida 1983). Other species taken by recreational boats include rainbow runner, *Elagatis bipinnulata*, kawakawa, *Euthynnus affinis*, and amberjack, *Seriola dumerili* (Sands 1980).

The nearshore fisheries are dependent upon a wide array of demersal and benthopelagic species which include pink snappers, *Pristipomoides filamentosus* and *P. sieboldii*; gray snapper, *Aprion virescens*, red snappers, *Etelis carbunculus* and *E. coruscans*; jacks, Carangidae; goatfishes, *Mulloidichthys* spp. and *Parupeneus* spp.; and sea bass, *Epinephelus quernus*. Bigeye scad, *Selar crumenophthalmus*, and mackerel scad, *Decapterus macarellus*, are also major species in this group and their combined landings are second only to tuna and billfish total landings (Uchida 1983). Recreational boats also catch needlefish, Belonidae, barracuda, *Syphyraena barracuda*, bonefish, *Albula vulpes*, and leatherback, *Scomberoides sancti-petri* (Sands 1980).

Species of fishes taken off Kahe Point and sold commercially are listed in Table 2. The most common commercially important species of fish (those with average annual catches of >1 metric ton) include tuna, billfish, dolphin, scad, snapper, jack, and goatfish (Table 3). The catches of all species are low compared with the State landings. The skipjack tuna and dolphin catches represent 5 and 6%, respectively, of the State landings for these species. The catch of each of the other species range from 0.2 to 2.2% of the State landings. Of the important deep demersal species, such as pink, red, and gray snappers, which are among the top 11 species in the State landings, the catch by species did not exceed 400 kg per year. The total catch of these snappers off Kahe Point (729 kg) is approximately 0.5% of the State landings for this group of fishes. The low catches of all species indicate that the area off Kahe Point supports only a limited resource of fish.

2. Effects on eggs, larvae, and juveniles

a. Impingement

Impingement will depend, among other things, on the velocity of water at the intake and the swimming capability (speed and endurance) of the fish. At an intake velocity of 0.25-0.30 m/s, none of the adult pelagic fishes taken commercially in the Kahe Point area is expected to be impinged on the warmwater intake screen. Adults of some mesopelagic fishes, such as myctophids, which migrate to surface waters at night, could be impinged on the warmwater intake screen, but these fishes are not utilized commercially. Impingement of adult fish could occur at the cold-water intake screen. All fish impinged there will be small mesopelagic forms that are relatively weak swimmers. The quantity of fish impinged should be far less than 43 kg per day (Section IIIA), since many of the small adults will easily pass through the screen. Thus, there should be no immediate effect on the fisheries from impingement on either the warm or cold water intake screen.

Table 2.--Local, common, and scientific names of fishes commonly caught in Hawaii off Kahe Point (Sands 1980; Uchida 1983).

Local name	Common name	Scientific name
A'awa	Spot wrasse	Bodianus bilunulatus
Ahaaha	Needlefish	Belonidae (3 species)
Ahi (menpachi shibi)	Bigeye tuna	Thunnus obesus
Ahi (kihada)	Yellowfin tuna	Thunnus albacares
Aholehole	Mountain bass	Kuhlia sandvicensis
Aku	Skipjack tuna	Katsuwonus pelamis
Akule	Bigeye scad	Selar crumenophthalmus
Alaihi	Squirrelfish	Holocentridae
Amaama	Mullet	Mugil cephalus
A'u (kajiki)	Pacific blue marlin	Makaira nigricans
A'u (naraigi)	Striped marlin	Tetrapturus audax
A'u ku	Broadbill swordfish	Xiphias gladius
A'u (indianfish)	Shortbill spearfish	Tetrapturus angustirostris
A'u	Black marlin	Makaira indica
A'u lepe	Sailfish	Istiophorus platypterus
Awa	Milkfish	Chanos chanos
Awaawa	Tenpounder	Elops hawaiensis
Aweoweo	Red bigeye	Priacanthidae
Ehu	Red snapper	Etelis carbunculus
Hahalalu	Small bigeye scad	Selar crumenophthalmus
Hanui	Parrotfish	Scaridae
Hinalea	Wrasse	Labridae
Humuhumu	Triggerfish	Balistidae
Kahala	Amberjack	Seriola dumerili
Kaku	Barracuda	Sphyraena barracuda
Kala	Surgeonfish	Naso unicornis
Kalikali	Pink snapper	Pristipomoides sieboldii
Kamanu	Rainbow runner	Elagatis bipinnulatus
Kawakawa	Kawakawa	Euthynnus affinis
Kole	Surgeonfish	Ctenochaetus strigosus
Kumu	Red goatfish	Parupeneus porphyreus
Kupoupou	Mongoosefish	Cheilio inermis
Laenihi	Razorfish	Xyrichthys pavo
Lai	Leatherback	Scomberoides sancti-petri
Lehi	Snapper	Aphareus rutilans
Mahimahi	Dolphin	Coryphaena hippurus
Maiii	Surgeonfish	Acanthuridae
Maiki	Surgeonfish	Acanthurus nigroris
Makiawa	Round herring	Etrumeus micropus
Malu	Goatfish	Parupeneus pleurostigma
Manini	Convict tang	Acanthurus sandvicensis
Mano kihikihi	Hammerhead shark	Sphyrna lewini
Maomao (mamo)	Damselfish	Abudefduf abdominalis
Moano	Goatfish	Parapeneus multifasciatus
Moi	Threadfin	Polydactylus sexfilis

Table 2.--Continued.

Local name	Common name	Scientific name
Moilua	Red goatfish	*Mulloidichthys pflugeri*
Mu	Porgy	*Monotaxis grandoculis*
Naenae	Orange spot tang	*Acanthurus olivaceus*
Nenue	Rudderfish	*Kyphosus bigibbus*
Nohu	Scorpionfish	*Scorpaenopsis cacopsis* and *S. gibbosa*
Nunu	Trumpetfish	*Aulostomus chinensis*
Oililepe	Filefish	*Alutera scripta*
Oio	Bonefish	*Albula vulpes*
Omaka	Jack	*Caranx mate*
Onaga	Red snapper	*Etelis coruscans*
Oopuhue	Balloonfish	*Arothron hispidus*
Opakapaka	Pink snapper	*Pristipomoides filamentosus*
Opelu	Mackerel scad	*Decapturus macarellus*
Opule	Spotted wrasse	*Anampses cuvieri*
Pakii	Flounder	*Bothus mancus* and *B. pantherines*
Palani	Surgeonfish	*Acanthurus dussumieri*
Panuhunuhu	Parrotfish	Scaridae
Panunu	Parrotfish	Scaridae
Paopao	Yellow jack	*Gnathanodon speciosus*
Pualu	Surgeonfish	*Acanthurus xanthopterus*
Puhi	Eel	Muraenidae
Saba	Japanese mackerel	*Scomber japonicus*
Taape	Blueline snapper	*Lutjanus kasmira*
Toau	Red-green snapper	*Lutjanus vaigiensis*
Uhu	Parrotfish	Scaridae
Ukikiki (gindai)	Brigham's snapper	*Pristipomoides zonatus*
Uku	Gray snapper	*Aprion virescens*
Ulaula (ehu)	Red snapper	*Etelis carbunculus*
Ulua kihikihi	Threadfin jack	*Alectis ciliaris*
Uouoa	False mullet	*Neomyxus chaptalii*
Uu (menpachi)	Squirrelfish	*Myripristis* spp.
Uukanipo	Squirrelfish	Holocentridae
Walu	Oilfish	*Ruvettus pretiosus*
Weke	Goatfish	*Mulloidichthys samoensis*
Weke ula	Red goatfish	*Mulloidichthys auriflamma*

Impingement at the warmwater intake screen will affect juveniles of epipelagic fishes, such as scombrids, billfishes, dolphins, wahoo, bonefishes, barracudas, some jacks, and some inshore fishes, such as goatfish, damselfish, filefish, squirrelfish, triggerfish, and rudderfish, which at times are found also in offshore surface waters. The smallest juveniles impinged will vary by species depending upon their body types.

Table 3.--Five-year (1976-80) mean annual catches of fish (>1 mt) taken off Kahe Point, Hawaii (Uchida 1983).

Species	Weight (kg)	Value of catch sold (in dollars)
Skipjack tuna (aku)	164,058	215,755
Yellowfin tuna (ahi)	14,899	40,490
Pacific blue marlin (a'u, kajiki)	8,106	13,533
Bigeye scad (akule)	6,887	17,422
Young bigeye scad (hahalalu)	3,435	7,798
Dolphin (mahimahi)	3,339	16,502
Striped marlin (a'u, naraigi)	2,297	4,658
Blueline snapper (taape)	1,687	1,991
Goatfish (weke)	1,371	2,134
Jack (ulua)	1,131	3,462
Red goatfish (weke-ula)	1,033	3,057
Total	208,249	326,802
Other fish	9,228	22,316
Total all fish	217,477	349,118

Among the slender bodied fish, those with body length to depth ratio of about 3:1 (scombrids, billfishes, dolphins, wahoo, barracudas, some jacks, goatfishes, etc.), impingement could occur at sizes as small as 4 cm. Others, juveniles with deeper bodies (some jacks, surgeonfish, squirrelfish, damselfish, etc.), could be impinged at even smaller sizes, perhaps around 2 cm. At these sizes, most juveniles will not be strong enough swimmers to escape impingement. Although juveniles of such fishes as the tunas are considered strong swimmers, no studies have yet been made to measure their swimming ability. One study of a closely related fish, Pacific mackerel, has been made (Hunter 1980) which shows that juveniles up to 3.6 cm long can swim at burst speeds of 26 cm/s. At this speed, which is within the range of the intake velocity, the juveniles would be able to barely maintain their position at the intake opening. Any juvenile caught in this position will eventually become impinged as fatigue sets in. Juveniles 4.0 cm long may suffer the same fate.

There are no published data on swimming speeds of larger juveniles, nor of the density of such juveniles off Kahe Point. Although juvenile tunas have been caught off Kahe Point in midwater trawls (Higgins 1970), all juveniles, with the exception of one 47-cm specimen, were smaller than 23 cm. Consequently, these will be considered together with the larvae. Juveniles of other species were not analyzed.

Although it can be assumed that all juveniles impinged on the screen will suffer mortality, the maximum size of juveniles that would be impinged has not been determined. Thus, estimates of losses due to impingement cannot be made.

b. Primary entrainment

Effects of primary entrainment on fish eggs and larvae of most commercially important fish species off Kahe Point are difficult to assess, owing to the absence of adequate vertical distribution and density data. The study by Miller et al. (1979) is the only one in which fish larvae have been identified to family or lower levels. However, because sampling was limited to shallow inshore waters, their results may have only limited application for assessing the kinds and density of larvae in the projected OTEC plantsite off Kahe Point. Miller et al. (1979) sampled off Kahe Point at 0.1-0.2 nmi from shore in 3-5 m of water ("inshore" stations) and at about 0.8 nmi in 27-128 m ("offshore" stations). The list of larvae identified (Table 4) includes five species (Chanos chanos, Coryphaena hippurus, Abudefduf abdominalis, Thunnus albacares, and Euthynnus affinis) and larvae of five other families (Kyphosidae, Labridae, Mullidae, Scorpaenidae, and Tetraodontidae) which are utilized commercially. It also includes 31 species (including 13 unidentified types of gobies) that are not utilized commercially. Approximately 90+ species utilized commercially were not taken in their plankton tows.

In another study which included intensive sampling off Kahe Point at approximately 0.2-0.6 nmi from shore, Miller (1979) obtained a mean abundance of 7.7/1,000 m^3 of tuna larvae in daytime surface tows and as high as 441/1,000 m^3 of yellowfin tuna in night tows, the latter being one to two orders of magnitude higher than the average open ocean densities. Miller hypothesized that the high nearshore density of tuna larvae probably was the result of nearshore upwelling accompanied by an onshore movement of deeper waters. Whatever the cause of the concentration of yellowfin tuna larvae at Kahe Point, the extremely high density reported by Miller is most likely a local phenomenon and is not representive of offshore waters. In open ocean sampling for tuna larvae in Hawaiian waters (unpublished data, Honolulu Laboratory) skipjack tuna larvae dominated the catches of tuna larvae in surface tows. The density of skipjack tuna larvae was 3.02/1,000 m^3 and that of yellowfin tuna larvae was 1.47/1,000 m^3.

The density of skipjack and yellowfin tuna larvae in open ocean waters obtained from plankton nets compares favorably with the density estimates of juvenile tunas obtained by Higgins (1970). Higgins used a midwater trawl consisting of 1.9-cm mesh netting and a mouth opening of 96 m^2. The net had a cod end liner made of 0.63-cm mesh netting and an opening of 7.5 m^2. Tows were made at two sites off Oahu (the inshore stations were 1.4 km north of Kahe Point), 7 and 56 km from shore, in the vicinity of the projected OTEC plantsite. The catch included skipjack and yellowfin tunas ranging in size from 7 to 26 mm, and one juvenile skipjack tuna 47 mm long. The density of young skipjack tuna was 2.4/1,000 m^3 and that of yellowfin tuna was 0.74/1,000 m^3. The densities of both species are somewhat underestimated since many larvae below 8 or 9 mm were suspected of having passed through the 0.63-cm netting.

Table 4.--Fish larvae taken off Kahe Point in plankton net tows (larvae/1,000 m^3 (Miller et al. 1979).

Family	Species	Inshore Winter	Inshore Summer	Offshore Winter	Offshore Summer
Dussumieriidae	Spratelloides delicatulus	--	--	--	--
Engraulidae	Stolephorus buccaneeri	--------(Several specimens)-----			
Chanidae	Chanos chanos	--------- (Never abundant)------			
Gonostomatidae	Cyclothone sp.	1.8	11.0	0.9	0
	Vinciguerria nimbaria	6.1	4.4	0	0
Myctophidae	Ceratoscopelus warmingi	0	5.7	0.9	1.4
	Hygophum proximum	1.8	0	0	0
	Lampadena spp.	0	0.7	0.9	0
Exocoetidae	Cypselurus spp.	1	1.5	0	0.7
Atherinidae	Pranesus insularum	--------(1 larva per tow)------			
Kyphosidae[1]	--	---(Several larvae in July)---			
Mullidae[1]	--	0	16.2	0	8.1
Serranidae	--	--------------(Some)-----------			
Coryphaenidae[1]	Coryphaena hippurus	21.1	0	0	0
Pomacentridae[1]	Abudefduf abdominalis	5.3	3.7	2.8	37.0
	Eupomacentrus fasciolatus	6.1	0.7	0	0
Labridae[1]	Labrid L-3	------------(1 larva)----------			
Scombrolabracidae	Scombrolabrax heterolepis	-(Some larvae in fall-winter)-			
Scombridae[1]	Auxis sp.	0	0	0	0.7
	Thunnus albacares	0	1.3	0	0
	Euthynnus affinis	-------(At two stations)-------			
Gobiidae	13 types	0	0	2.8	0.7
	Psilogobius mainlandi	0	2.1	0	0
Tripterygiidae	--	8.7	4.0	0.8	0
Blenniidae	Enchelyurus brunneolus	0	20.2	1.9	36.0
	Exallias brevis	0	46.0	1.0	11.4
Schindleriidae	Schindleria pietchmanni	0.9	1.3	0	0
Scorpaenidae[1]	Scorpaenid S-3	Few	Few	Few	Few
Tetraodontidae[1]	--	0	2.2	0	0.7
Molidae	Ranzania laevis	-------(Few in spring)-------			

[1]Adults caught commercially.

Because the size range of larvae taken in plankton nets complements that of larvae and juveniles taken in midwater trawl, the densities derived from both gear should provide rough estimates of the numbers of young tunas that could be entrained in the warmwater intake. Thus, based on the combined density of 5.42/1,000 m^3 for skipjack tuna and 2.21/1,000 m^3 for yellowfin tuna, and on the volume of water passing through the plant each day (13.8 million m^3), roughly 75,000 skipjack and 30,000 yellowfin tuna larvae and juveniles could be entrained daily. Since tunas spawn from late spring to early autumn in Hawaiian waters (about 6 months), roughly 13.7 million skipjack and 5.5 million yellowfin tuna larvae and juveniles could be entrained in the warmwater intake seasonally (= annually).

Entrainment estimates can be made for billfishes also. Using the density value of 0.579/1,000 m^3 for billfishes (Pacific blue marlin, sailfish, and shortbill spearfish) in Hawaiian waters (Matsumoto and Kazama 1974), the daily entrainment could be about 8,000. The annual entrainment could be about 1.4 million since spawning extends from May through October.

Estimates of entrainment of larvae of other commercially important fishes cannot be made due to the lack of information on the identity and density of many bottom-associated as well as pelagic species.

Free floating fish eggs in the ocean are concentrated near the surface, and the density of eggs decreases sharply with depth. Catch data from oblique plankton net tows made off Kahe Point (Noda et al. 1981) indicate that about 72% of the eggs (all species) were in the upper 25 m, 24% in the 25-200 m depth range and 4% in the 200-1,000 m depth range. The density of eggs in the top 1 m of water (based on neuston net catches) was nearly twice the average for the 0-25 m depth layer (213,000/1,000 m^3 vs. 117,000/1,000 m^3). Because the distribution of eggs is skewed toward the surface and the intake is located in the lower half of the 0-25 m depth layer, the density of eggs at the intake level should be well below a third (<39,000/1,000 m^3) that of the depth layer. Based on the 13.8 million m^3 of water expected to be drawn into the plant each day, the number of eggs entrained daily could be about 538 million.

The impact on the fishery resulting from the loss of this many eggs cannot be measured accurately, since the eggs had not been identified and quantified by species. Nevertheless, in view of the tremendous spawning capacity of some of the pelagic fishes [e.g., yellowfin tuna, 2-8 million (June 1953); skipjack tuna, 100,000-2 million (Matsumoto et al. in press); kawakawa, presumably similar to skipjack tuna; striped marlin, 2-28 million (Ueyanagi and Wares 1975); blue marlin, presumably similar to striped marlin; sailfish 2-20 million (Beardsley et al. 1975); shortbill spearfish, 2-6 million (Kikawa 1975)], and the expected losses representing only a minor portion of the total eggs in the area, the projected egg losses due to OTEC plant operations should have no drastic effects on the fishery.

In summary, biocides used in strong enough concentration to kill biofouling organisms could also kill fish eggs and larvae; however, because the EPA restricts the discharge of chlorine to 2 h each day, the mortality from this source should be limited. Total or near total mortality of eggs and larvae and up to 68% mortality of entrained juveniles could occur from thermal effects and physical damages suffered during passage through the pumps, and from collision with structures and other organisms. Larvae and juveniles surviving through the discharge will be physically weak and be especially susceptible to predation. Consequently, the assumption of total mortality of all fish eggs, larvae, and juveniles entrained is not unreasonable.

In a worst case situation, assuming 100% mortality of the young, exclusive of eggs, the losses from primary entrainement of the three most important fishes or fish groups taken off Kahe Point would be 13.7 million skipjack tuna, 5.5 million yellowfin tuna, and 1.4 million billfishes per year. The damage to other pelagic and demersal fishes caught commercially cannot be determined until their eggs and larvae are identified and density estimates are obtained.

c. Secondary entrainment

Damage to fish eggs and larvae entrapped in the discharge could result mainly from thermal shock and the impact and turbulence of the discharged water. Although the number of larvae affected could be large, due to the magnitude of the discharge volume, an accurate assessment cannot be made without more detailed data on the distribution of eggs and larvae near the discharge depth, the strength of the impact, the intensity of acceleration and shear forces in the eddies, and the timespan these forces will be acting upon the eggs and larvae at lethal levels. Available data only permit very rough estimates.

Eggs and larvae of tunas and marlins generally occupy the surface and near surface waters. Only a small fraction is found in depths greater than 60 m (Matsumoto 1958; Strasburg 1960; Matsumoto and Kazama 1974). Strasburg (1960) estimated that 75-80% of the tuna larvae in the central Pacific equatorial waters occurred in the 0-60 m depth range, 20-25% in 70-130 m, and none in depths greater than 130 m. Assuming a similar vertical distribution in Hawaiian waters, about 2.7-3.4 million skipjack tuna and 1.1-1.4 million yellowfin tuna larvae could be entrained in the discharge each year.

Larvae of other fishes utilized commercially off Kahe Point, such as dolphin, jacks, and goatfish, also may be concentrated near the surface, since their eggs are buoyant. Very little is known about the eggs and larvae of snappers; however, a study by Kikkawa (1980) on the spawning season of the pink snapper, Pristipomoides filamentosus, indicates that ripe eggs of this species contain oil globules. Eggs of other species of snappers would most likely contain oil globules also. Such eggs are buoyant and, therefore, would be concentrated near the surface, similar to eggs of tunas, marlins, dolphins, and jacks. Consequently, the hatched larvae would likewise be concentrated near the surface. Larvae of those species mentioned above would be sparsely distributed near the discharge depth so that even at 100% mortality during secondary entrainment, the negative effects to the fishery should be minimal.

d. Effects by all categories

Because the eggs of most fishes caught commercially off Kahe Point are buoyant, and eggs and larvae are concentrated near the surface, most of the damage will occur during primary entrainment. Eggs and larvae could suffer total mortality, so that larvae of approximately 13.7 million skipjack tuna, 5.5 million yellowfin tuna, 1.4 million billfish, and an unknown quantity of other pelagic, reef-associated, and demersal fishes could be killed each year. Damage from secondary entrainment could account for an additional 3.4 million skipjack and 1.4 million yellowfin tuna larvae. Other losses could occur from impingement of juveniles at the warm intake screen. Because of their strong swimming capability, however, kills from impingement are expected to be small for tunas. Juveniles of slow swimming reef and bottom fishes, however, could be affected more seriously. No estimate of potential damage to juveniles from impingement can be made at this time.

Although the total damage to all commercially important fishes off Kahe Point cannot be assessed accurately, rough estimates of damages from primary and secondary entrainment can be made for the two groups of fishes that together contribute 87.5% of the commercial catch off Kahe Point. Thus, at least 17.1 million skipjack tuna, 6.9 million yellowfin tuna, and 1.4 million billfish larvae could be killed annually, assuming the worst condition.

3. Effects of attraction

Studies of fish aggregating devices (FADs) show that large build up of fish schools can occur around objects floating in the ocean (Matsumoto et al. 1981). Although most fish attracted to the FADs are small, i.e., juveniles and preadults which tend to be longer term dwellers, large fish also congregate temporarily. Similar build up of fish schools can occur also around stationary objects such as the OTEC plant (Seki 1983). The attraction of fish schools could be of considerable benefit to recreational and commercial fishermen by enabling them to increase catches, while at the same time reducing fuel consumption.

There are some negative effects to attraction, particularly by an OTEC plant. With the accumulation of large fish around the plant, spawning will eventually take place as the fish mature sexually during the season. This will increase the density of eggs and larvae around the plant and ultimately result in raising the number of larvae killed by entrainment. The discharge plume also could attract fish that could prey upon larvae and juveniles that are damaged and weakened by the impact and turbulence of the effluent. The predation level thus could rise and increase the mortality of larvae and juveniles.

4. Effects on recruitment

The effects of egg and larval mortality from OTEC plant operations on the recruitment of fish into the fishery will vary greatly by species. For such fish as the tunas and billfishes, which are highly migratory and spawn widely throughout the tropical and subtropical waters, egg and larval mortality at isolated points, such as around OTEC plants, will have little or no impact on the adult population at the plantsite. This is based on the following observations. First, a large proportion (50-90%) of the adults that comprise the skipjack tuna fishery in Hawaii are 60 cm or larger (Rothschild 1965). These fish are migrants, some arriving from the eastern Pacific northern fishery, a portion from the northwestern Pacific, and others from equatorial waters to the south (Matsumoto et al. in press).

It is generally accepted that these fish originate largely from spawnings in equatorial waters and consequently, egg and larval mortality at the Kahe Point site will have little influence on the size of the adult population there. Second, a portion of the skipjack tuna below 60 cm, representing age group 1-1+, could originate in Hawaiian waters, since there is ample evidence of the presence of small (30-37 cm) fish there throughout the winter months (Matsumoto et al. 1981). The effects of egg and larval mortality off Kahe Point, however, may not be noticeable in this age group because larvae originating there do not necessarily return to that particular site. Instead the return is made to Hawaiian waters in general. Moreover, as in the larger size group, some of the fish migrate from the south as seasonal warming moves northward. Third, most of the eggs and larvae that are expected to be killed by OTEC plant operation would have died eventually from natural causes. Hence the actual kill due solely to OTEC plant operations would be the estimated total minus the losses expected from natural mortality.

Natural mortality rates (M) of eggs and larvae of tunas have not been determined precisely, but published estimates of M for tunas taken in various fisheries have been reviewed by Murphy and Sakagawa (1977). They indicate that the range of M is 0.67-0.91 for yellowfin tuna and 0.69-0.93 for skipjack tuna, and the mean for both species is approximately 0.8. Since M is greatly underestimated for larvae and juveniles, it would be reasonable to use the higher M for both species. The net losses due to OTEC plant operations thus would be approximately 1.2 million skipjack tuna and 0.6 million yellowfin tuna.

For other fish, such as reef and deep demersal types, the effect on recruitment cannot be measured until eggs and larvae have been identified and more complete information about their biology and ecology has been obtained.

5. Recent developments

The discussion above was based on OTEC plant placement between 1 and 2 mi offshore, and the discharge located at a depth of about 100 m and well away from the bottom. Recent development in planning indicates that the plant could be located within 1 mi from shore at a depth of 50 m. The discharge is to be led through a pipe to the 100-m ledge, and released in a downward trajectory over the escarpment, where the depth drops off from 100 to 900 m over a distance of 4.6 km. The warmwater intake facing shoreward at the plantsite will have a mouth opening 20 m wide and 30 m deep so that it will be 10 m below the surface and 10 m off the bottom. In addition to the surface water, warm effluent from the existing electric powerplant will be utilized to heat the working fluid. This powerplant effluent contains some sand, which eventually will be discharged in the OTEC plant effluent. The sedimentation caused by the effluent thus will be a new element affecting the environment near the discharge point.

There should be little change in the eggs and larvae entrained in the warmwater intake system, but major changes could occur to the bottom fauna below the discharge point. There will be a buildup of sand on the escarpment which could change the habitat from rocky to sandy bottom of choice market fish, such as the snappers. These fish, which occupy a depth range of 70 to 300 m (Ralston 1980), thus could be driven off the discharge area. Although the immediate effects may not be severe, the affected area could become extensive over time and eventually drive out these fish from large tracts of bottom.

B. Puerto Rico

1. Fisheries

The fishery in Puerto Rico is largely an inshore fishery which in 1978 produced 2.5 million kg of finfish (Weiler and Suarez-Caabro 1980). Fishing is done from small boats, usually <7.6 m (25 ft) long, and with gear requiring few men. In 1978 the highest production was from fish pots (53.3%), followed in order by handline (20.7%), troll (8.7%), gill net (8.2%), beach seine (7.7%), and others (1.4%); and the production, by coast were: west (46%), south (25%), east (20%), and north (9%).

On the east coast, where the OTEC plant will be located, the principal fishes taken are various species of groupers (Serranidae) 25%, grunts (Pomadasyidae) 19%, and snappers (Lutjanidae) 18%. Other fishes taken in much smaller quantities are mackerels (Scomberomorus) 6%, goatfish (Mullidae) 5%, triggerfish (Balistidae) 5%, and porgy (Sparidae) 4%. The remainder, which includes trunkfish (Ostraciidae), wrasse (Labridae), parrotfish (Scaridae), barracuda (Sphyranidae), tunas (Scombridae), jacks (Carangidae), mullet (Mugilidae), and half-beak (Hemiramphidae), account for 18% of the production.

2. Effects on fisheries

The effects on fisheries off Punta Tuna on the east coast would be similar to those off Kahe Point, Hawaii. Eggs and larvae of pelagic fishes, such as tunas, billfishes, mackerels, some jacks, and some demersal fishes with buoyant eggs, such as snappers, will be minimally affected by OTEC plant operation. As in Hawaii, very little is known about the biology of most reef- and bottom-dwelling forms. Consequently, the extent of damage to eggs and larvae of these fishes cannot be estimated. Some minor changes could occur to the environment inhabited by the adults of the three most important fishes. Groupers, grunts, and snappers normally are found in depths ranging from 75 to 290 m in Hawaii. If these fishes occur in similar depths off Puerto Rico, they would most likely be found in water ranging from 23° to 13.5°C. Since the discharge temperature is 15.5°C water at a depth around 100 m, there would be a lowering of the habitat temperature by about 8°C or less. This could force the groupers, and perhaps the porgies also, to move away from the site of the outfall.

Indirect effects could occur from increased primary production at the discharge depth. Whether this will be beneficial or detrimental to the demersal fish species has yet to be determined.

V. SUMMARY AND CONCLUSION

This document presents a review of pertinent operating conditions of a 40 MW OTEC pilot plant presently being planned for sites off Kahe Point, Hawaii, and Punta Tuna, Puerto Rico, the factors that may affect the fisheries, and the fisheries affected at the two sites.

At Kahe Point, the probable plantsite will be slightly <1 mi from shore at a depth of 50 m. The warmwater intake will be at a depth of 10-30 m and the cold water intake at a depth of 800-900 m. The mixed water will be discharged at a depth of 100 m in a downward trajectory over an escarpment where the depth drops from 100 to 900 m over a distance of 4.6 km.

The flow rate for the warmwater intake will be about 4 $m^3/s/MW$ or roughly 13.8 million m^3/day for a 40 MW plant. A similar flow rate is expected in the cold water intake.

The plant operation is expected to affect the fisheries in several ways: large juveniles and small, weak-swimming adults will be impinged on the intake screen; eggs and larvae and small juveniles capable of passing through the intake screen will be entrained and exposed to sudden changes in temperature, biocides, and physical damage; and eggs and larvae would be exposed to these same factors in the discharge plume.

As in existing powerplant operations, physical stresses inflicted upon fish eggs and larvae during passage through the OTEC plant will be the major cause of damage. Mortality from these causes could be high (up to 100%), whereas, mortality due to biocide treatment and rapid changes in temperature could be negligible.

The principal fisheries off Kahe Point that would be affected by OTEC plant operations include those of six pelagic and two demersal fish groups representing 98% of the area's total annual production. The pelagic forms include: tuna (mainly skipjack and yellowfin), billfish (Pacific blue and striped marlin), dolphin, wahoo, bonefish, and jacks (principally scad). The demersal forms include goatfish (six species) and snappers (eight species).

Based on density values of tuna and billfish larvae at depths near the warm intake and discharge points, rough estimates of the extent of damage from plant operations can be made. Assuming total mortality during entrainment, 17.1 million skipjack and 6.9 million yellowfin tuna larvae could be killed each spawning season. Adjusting these values to reflect losses due to natural mortality (assuming M of 0.93 for skipjack tuna and 0.91 for yellowfin tuna), the net loss due strictly to plant operations would be approximately 1.2 million skipjack and 0.6 million yellowfin tuna larvae. Calculations for billfish larvae yields an estimate of 1.4 million killed per season. The net loss due to plant operations cannot be estimated since M is not known for these species. Estimates of damages to other fish larvae in the Kahe Point area cannot be made due to lack of pertinent information.

The OTEC plant is expected to function as a FAD and attract fish from adjacent areas. Any build up of large aggregations of fishes, such as tunas, dolphins, mackerels, and carangids will eventually result in concentrated spawnings around the plant, subjecting more than the usual amounts of eggs and larvae to entrainment effects.

Effects of OTEC plant operations on the fisheries will be largely through the recruitment process. The effects of recruitment on pelagic species, particularly tunas, will not be noticeable because most of them are migrants from the eastern Pacific fishery, the northwestern Pacific, and from equatorial waters. The effects of recruitment on bottom and reef-associated fishes would most likely be felt in areas farther downstream from the plantsite. Because the prevailing currents carry the eggs and larvae along the coast and out into open ocean, the full impact of the damages caused by the plant may not be apparent at the plantsite.

Direct effects could occur in the demersal fishery. If the warm effluent from the existing powerplant is also used to heat the working fluid, the sand particles contained in this effluent will eventually be discharged over the escarpment. The sand particles could build up and, over a period of time, blanket the rocky bottom near the discharge point and thus force such species as the snappers, groupers, and grunts to relocate in other areas. The net effect to the fishery should be negligible, however, since these species comprise only a small portion (1.3%) of the total fish production off Kahe Point.

The principal fisheries off Punta Tuna include four demersal and one pelagic fish group representing 72% of the fish taken along the eastern coastline. The demersal group includes: groupers (14 species), grunts (11 species), snappers (14 species), and porgies (3 species); and the pelagic group is composed of mackerels (2 species). Other pelagic fishes, such as tunas, marlins, dolphins, and jacks, comprising 1.8% of the total fish production, are caught in small numbers.

The effects of OTEC plant operations on pelagic fishes off Punta Tuna will be insignificant. The effects on demersal and reef fishes cannot be estimated in the absence of appropriate data and biological information.

LITERATURE CITED

Alderson, R.

1972. Effects of low concentrations of free chlorine on eggs and larvae of plaice, Pleuronectes platessa L. In M. Ruivo (editor), Marine pollution and sealife, p. 312-315. Fishing News (Books) Ltd., Lond.

1974. Seawater chlorination and the survival and growth of the early developmental stages of plaice, Pleuronectes platessa L. and Dover sole, Solea solea L. Aquaculture 4:41-53.

Austin, H. M., A. D. Sosnow, and C. R. Hickey, Jr.
1975. The effects of temperature on the development and survival of the eggs and larvae of the Atlantic silverside, Menidia menidia. Trans. Am. Fish. Soc. 104:762-765.

Beardsley, G. L., Jr., N. R. Merrett, and W. J. Richards.
1975. Synopsis of the biology of the sailfish, Istiophorus platypeterus (Shaw and Nodder, 1971). In Shomura, R. S. and F. Williams (editors), Proc. Intern. Billfish Symp. Pt. 3. Species Synopses. NOAA Tech. Rep. NMFFS SSRF-675:95-120.

Blaxter, J. H. S., and D. E. Hoss.
1979. The effect of rapid changes of hydrostatic pressure on the Atlantic herring Clupea harengus . II. The response of the auditory bulla system in larvae and juveniles. J. Exp. Mar. Biol. Ecol. 41: 87-100.

Coutant, C. C., D. K. Cox, and K. W. Morred, Jr.
1976. Further studies of cold-shock effects on susceptibility of young channel catfish to predation. In G. W. Esch and R. W. McFarland (editors), Thermal Ecology II, p. 154-158. Tech. Info. Ctr., Off. Info. Serv., Energy Res. and Develop. Admin.

Griffith, J. S.
1976. EFfects of low temperature on survival and behavior of threadfin shad, Dorosoma petenense. Trans. Am. Fish. Soc. 107:63-70.

Higgins, B. E.
1970. Juvenile tunas collected by midwater trawling in Hawaiian waters, July-September 1967. Trans. Am. Fish. Soc. 99:60-69.

Hoss, D. E., and J. H. S. Blaxter.
1979. The effect of rapid changes of hydrostatic pressure on the Atlantic herring, Clupea harengus L. I. Larval survival and behaviour. J. Exp. Mar. Biol. Ecol. 41:75-85.

Hoss, D. E., and D. S. Peters.
1983. Synthesis of pertinent information on the potential effects of estuarine and coastal powerplants on fisheries with comments on how this information might apply to ocean thermal energy conversion (OTEC) operations. Southeast Fish. Cent. Beaufort Lab., Natl. Mar. Fish. Serv., NOAA, Beaufort, NC 28516, 52 p.

Hoss, D. E., D. S. Peters, and R. E. Rose.
1983. Study of the potential impact to fisheries of OTEC operations. Task 2a. Summary report of pertinent biological information from the Caribbean. Southeast Fish. Cent. Beaufort Lab., Natl. Mar. Fish. Serv., NOAA, Beaufort, NC 28516, 111 p.

Hunter, J. R.
1980. Feeding ecology and predation of marine fish larvae, p. 33-77. In R. Lasker (editor), Marine Fish Larvae, Wash. Sea Grant Program, Seattle.

June, F. C.
1953. Spawning of yellowfin tuna in Hawaiian waters. U.S. Fish. Wildl. Serv., Fish. Bull. 54:47-64.

Kikkawa, B. S.
1975. Synopsis on the biology of the shortbill spearfish, Tetrapturus angustirostris Tanaka, 1914, in the Indo-Pacific areas. In Shomura, R. S. and F. Williams (editors), Proc. Intern. Billfish Symp. Pt. 3. Species Synopsis. NOAA Tech. Rep. NMFS SSRF-675:49-54.

1980. Preliminary study on the spawning season of the opakapaka, Pristipomoides filamentosus. In R. W. Grigg and R. T. Pfund (editors), Proceedings of the Symposium on Status of Resource Investigations in the Northwestern Hawaiian Islands, Honolulu, Hawaii, April 24-25, 1980, p. 226-232. Sea Grant Misc. Rep. UNIHI-SEAGRANT-MR-80-04.

Lanza, G. R., G. J. Lauer, T. C. Ginn, P. C. Storm, and L. Zubarik.
1975. Biological effects of simulated discharge plume entrainment at Indian Point nuclear power station, Hudson River estuary, USA. In Proceedings of Symposium on Combined Effects of Radioactive, Chemical and Thermal Releases to the Environment, Stockholm, Sweden, June 9, 1975, p. 45-123. Internatl. Atomic Energy Agency, Vienna. STI/PUB/404.

Marcy, B. C., Jr., A. D. Beck, and R. E. Ulanowicz.
1978. Effects and impacts of physical stress on entrained organisms. In J. R. Schubel and B. C. Marcy, Jr. (editors), Power plant entrainment: A biological assessment, p. 135-188. Acad. Press, N.Y., Chapter 4.

Matsumoto, W. M.
1958. Description and distribution of larvae of four species of tuna in central Pacific waters. U.S. Fish. Wildl. Serv., Fish. Bull. 58:31-72.

Matsumoto, W. M., and T. K. Kazama.
1974. Occurrence of young billfishes in the central Pacific Ocean. In R. S. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12 August 1972. Part 2. Review and contributed papers, p. 238-251. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-675.

Matsumoto, W. M., T. K. Kazama, and D. C. Aasted.
1981. Anchored fish aggregating devices in Hawaiian waters. Mar. Fish. Rev. 43(9):1-13.

Matsumoto, W. M., R. A. Skillman, and A. E. Dizon.
In press. Synopsis of biological data on skipjack tuna, Katsuwonus pelamis.

Maynard S. D., F. V. Riggs, and J. F. Walters.
1975. Mesopelagic micronekton in Hawaiian waters: Faunal composition, standing stock, and diel vertical migration. Fish. Bull., U.S. 73:726-736.

Miller, J. M.
1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull. Mar. Sci. 29:19-26.

Miller, J. M., W. Watson, and J. M. Leis.
1979. An atlas of common nearshore marine fish larvae of the Hawaiian Islands. Sea Grant Misc. Rep., UNIHI-SEAGRANT-MR-80-02, 179 p.

Morgan, R. P., and E. J. Carpenter.
1978. Biocides. J. R. Schubel and B. C. March, Jr. (editors), Power plant entrainment: A biological assessment, p. 95-134. Acad. Press, N.Y., Chapter 3.

Morgan, R. P., R. E. Ulanowicz, V. J. Rasin, L. A. Noe, and G. B. Gray.
1976. Effects of shear on eggs and larvae of the striped bass, Morone saxatilis, and the white perch, M. americana. Trans. Am. Fish. Soc. 105:149-154.

Murphy, T. C., and G. T. Sakagawa.
1977. A review and evaluation of estimates of natural mortality rates of tunas. [In Engl., Fr. and Span. resume.] Collect. Vol. Sci. Pap., Int. Comm. Conserv. Atl. Tunas (SCRS-1976) 6:117-123.

Noda, E. K., and Associates.
1982. Current measurements off Kahe Point, Oahu in support of the OTEC program. Prepared for the Dep. Planning and Econ. Develop., State of Hawaii, Honolulu, var. pag.

Noda, E. K., P. K. Bienfang, W. J. Kimmerer, and T. W. Walsh.
1981. OTEC environmental benchmark survey, Kahe Point, Oahu. Final Report. Univ. Hawaii/Lawrence Berkeley Lab., Contract Rep. HNEI-81-05, var. pag.

Otto, R. G., M. A. Kitchel, and J. O. Rice.
1976. Lethal and preferred temperatures of the alewife (Allosa pseudoharengus) in Lake Michigan. Trans. Am. Fish. Soc. 105:96-106.

Ralston, S.
1980. An analysis of the Hawaiian offshore handline fishery: A progress report. In R. W. Grigg and R. T. Pfund (editors), Proceedings of the Symposium on Status of Resource Investigations in the Northwestern Hawaiian Islands, Honolulu, Hawaii, April 24-25, 1980, p. 204-215. Sea Grant Misc. Report UNIHI-SEAGRANT-MR-80-04.

Rothschild, B. J.
1965. Hypothesis on the origin of exploited skipjack tuna (Katsuwonus pelamis) in the eastern and central Pacific Ocean. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 512, 20 p.

Sands, M. D.
1980. Ocean thermal energy conversion (OTEC) programmatic environmental analysis. U.S. Dep. Energy, LBL-10511 (Vol. 1) (DE81030222), var. pag. Available Natl. Tech. Info. Serv., Springfield, VA 22161.

Schubel, J. R., and T. S. Y. Koo.
1976. Effects of various time-excess temperature histories on hatching success of blueback herring, American shad, and striped bass eggs, p. 165-170. In G. W. Esch and R. W. McFarlane (editors) Thermal Ecology II. Tech. Info. Ctr., Off. Info. Serv., Energy Res. & Develop. Admin.

Seki, M. P.
1983. Summary of pertinent information on the effects of artificial structures in tropical and subtropical waters. Southwest Fish. Cent. Honolulu Lab., Admin. Rep. H-83-12, Natl. Mar. Fish. Serv., NOAA, 49 p.

Serchuk, F. M.
1976. The effects of the Ludington Pumped Storage Power Project on fish passage through pump-turbines and on fish behavior patterns. Ph.D. dissertation. Mich. State Univ., Ann Arbor, Mich.

Strasburg, D. W.
1960. Estimates of larval tuna abundance in the central Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 60:231-255.

Sullivan, S. M., M. D. Sands, J. R. Donat, P. Jepsen, M. Smookler, and J. F. Villa.
1981. Environmental assessment. Ocean thermal energy conversion (OTEC) pilot plants. Prepared for Department of Energy by Lawrence Berkeley Laboratory, Berkeley, Calif., Contract. No. W-7405-ENG-48.

Tagatz, M. E.
1961. Tolerance of striped bass and American shad to changes of temperature and salinity. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 388, 8 p.

Uchida, R. N.
1983. Summary of pertinent biological characteristics of potential ocean thermal energy conversion (OTEC) sites on the Pacific Ocean. Southwest Fish. Cent. Honolulu Lab., Admin. Rep. H-83-13, Natl. Mar. Fish. Serv., NOAA, 85 p.

Ueyanagi, S., and P. G. Wares.
1975. Synopsis of biological data on striped marlin, Tetrapturus audax (Philippi), 1887. In Shomura, R. S. and F. Williams (editors), Proc. Intern. Billfish Symp. Pt. 3. Species Synopses. NOAA Tech. NMFS SSRF-675:132-159.

[U.S.] Environmental Protection Agency.
1976. Development document for best technology available for the location, design, construction and capacity of cooling water intake structures for minimizing adverse environmental impact. United States EPA 440/1-76/015-a, 263 p.

Venkataramiah, A., G. J. Lakshmi, C. Best, G. Gunter, E. Hartwig, and P. Wilde.
1981. Studies on toxicity of OTEC plant components on marine animals from the Gulf of Mexico. Lawrence Berkeley Laboratory, LBL-13915, 114 p.

Weiler, D., and J. A. Suarez-Caabro.
1980. Overview of Puerto Rico's small-scale fisheries statistics 1972-1978. Corporation for the Development and Administration of the Marine, Lacustrine and Fluvial Resources of Puerto Rico (CODREMAR), Fish. Res. Lab. Tech. Rep. 1, 27 p.

Wolters, W. R., and C. C. Coutant.
1976. The effect of cold shock on the vulnerability of young bluegill to predation. In G. W. Esch and R. W. McFarlane (editors), Thermal Ecology II, p. 162-164. Tech. Info. Ctr., Off. Info. Serv., Energy Res. and Develop. Admin.